Potential Grain and Forage Production of Early Maturing Pigeonpea in the Southern Great Plains

S. C. Rao,* W. A. Phillips, H. S. Mayeux, and S. C. Phatak

ABSTRACT

Forage-based livestock production is a significant component of the agricultural economy throughout the southern U.S. Great Plains. However, Livestock production in grazing systems is limited by low forage mass and quality from late July to early November. Pigeonpea (*Cajanus cajan* L. Millsp.) is a warm-season grain legume that may have potential as a summer forage crop. A 3-yr (1996–1998) field study was conducted near El Reno, OK, to assess the performance of two early maturing pigeonpea lines, Georgia-2 and ICPL 85010. The two lines did not differ significantly in forage and grain production and nutritive value. At 96 d after planting (DAP), total aboveground biomass was 5.2 Mg ha^{-1}, N content was 23 g kg^{-1}, and in vitro digestible dry matter (IVDDM) was 580 g kg^{-1} averaged across years. At final harvest (118 DAP), total dry biomass was 12.6, 6.4, and 9.3 Mg ha^{-1} in 1996, 1997, and 1998, respectively. Seed yield was 5.4, 1.9, and 1.2 Mg ha^{-1} in 1996, 1997, and 1998, respectively. Nitrogen concentration and IVDDM at final harvest was 19 and 585 g kg^{-1} for total plant biomass, 34 and 758 g kg^{-1} for leaves, 9 and 420 g kg^{-1} for stems, and 26 and 750 g kg^{-1} for seed, respectively. Early maturing pigeonpea lines can fill the forage deficit period during late summer and provide protein supplement for livestock.

Pigeonpea is an important grain legume crop grown in tropical and subtropical regions (Nene and Sheila, 1990). It can survive well in degraded soil and is drought tolerant. However, traditional varieties are highly sensitive to photoperiod (McPherson et al., 1985) and take from 175 to 280 d to reach maturity. In temperate regions, such varieties cannot be grown successfully because of exposure to frosts during the latter part of the growing season. In recent years, early maturing lines were developed at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). These new lines are relatively photoperiod insensitive and mature in 125 to 140 d (Singh et al., 1990). Ali (1990) reported that in northern India, early maturing pigeonpea lines can be successfully grown in rotation with winter wheat. Early and medium-maturing pigeonpeas were successfully used for cattle grazing as well as forage and seed production (Akinola and Whiteman, 1975).

It was recently demonstrated that Pigeonpea grain from early maturing line GA-2 can be used as a protein supplement for livestock (Phillips and Rao, 2001). The major market for good-quality pigeonpeas are for human consumption in most parts of Asia and Middle-eastern countries, but cracked and pinched grain and byproducts may be available for incorporation into animal feeds (Whiteman and Norton, 1981). Pigeonpea biomass and grain have been used as animal feed for centuries by Indian farmers (Whyte et al.,1953; Pathak, 1970). Febles and Padilla (1970) reported yields of >7.8 Mg ha^{-1} of green pods, roughly equivalent to 3.9 Mg ha^{-1} of grain, from high-yielding cultivars in Puerto Rico. Phatak et al. (1993) evaluated over 60 early and medium-maturing lines in Georgia and Mississippi that were acquired from ICRISAT. Six of the lines produced >4 Mg of grain ha^{-1}. Sheldrake and Narayanan (1979) reported pigeonpea grain yields of 0.5 to 1 Mg ha^{-1} yr^{-1} under limited rainfall, and 1.6 to 2.5 Mg ha^{-1} under more favorable growing conditions.

Because grain can be produced under relatively adverse climatic conditions, pigeonpea can be grown in areas not suitable for soybean [*Glycine max* (L.) Merr.] (Wallis et al., 1988). In addition, pigeonpea can also reduce soil erosion (Morton, 1976; Sheldrake and Narayanan, 1979; Ong and Daniel, 1990). The objective of the study was to determine the biomass and grain yields and nutritive value of two early maturing pigeonpea lines grown during the summer fallow period of continuous winter wheat production in the southern Great Plains.

MATERIALS AND METHODS

The study was conducted during the summer fallow period between continuous winter wheat crops at the Grazinglands Research Laboratory near El Reno, OK (35°40′ N, 98°00′ W, elevation 414 m). Soil on the experiment site was Dale silt loam (fine-silty, mixed, superactive, thermic, Pachic Haplustolls) with a pH of 6.6. Mean maximum and minimum temperatures at this location during the June to September growing season are 36°C and 20°C, respectively. The 25-yr mean average rainfall during the growing season (May to September) is 500 mm. Average date of the first killing frost (90% probability) is 11 November (Johnson and Duchon, 1995).

Two early maturing pigeonpea lines were selected for study. These were Georgia-2, developed at the University of Georgia, Tifton, GA; and ICPL 85010, which was developed at ICRISAT, Patancheru, A.P., India. Both lines are early maturing (110–140 d to reach maturity), photoperiod insensitive, short-statured, and determinate in growth habit. Following wheat grain harvest in June, plots were prepared with conventional tillage and 26 kg ha^{-1} of P were applied. No N fertilizer was applied. Each plot was 3-m wide and 20-m long, with three replications of each line. Seeds were inoculated with a multistrain inoculum commonly used for cowpeas and planted ≈2 cm deep at the rate of 30 kg ha^{-1} with a row spacing of 60 cm and an in-row spacing of 15 cm. Planting dates were 6

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Abbreviations: CGR, crop growth rate; DAP, days after planting; ICRISAT, International Crop Research Institute for the Semi-Arid Tropics; IVDDM, in vitro digestible dry matter; NIRS, near-infrared reflectance spectroscopy.

to 8 June in each of the years. Rainfall and ambient temperature were monitored continuously ≈50 m from the experiment site.

Whole aboveground plant samples were collected on five sampling dates from 30 to ≈118 DAP. Plants were clipped 2.5-cm above the ground at three randomly selected 0.5-m lengths of center rows in each plot (≈6 plants). Samples were collected at a new location on each sampling date. Plant samples were dried in a forced-draft oven at 65°C for at least 60 h or until constant dry weight was obtained. They were then weighed to determine dry matter content and separated into leaves and stems on the first two sampling dates and into leaves, stem, and seed on the last three dates. Crop growth rate (CGR) was determined by calculating the difference in biomass accumulation between sampling date divided by number of days between sampling. Plant components were ground in a Wiley mill equipped with 1-mm screen.

All plant components were analyzed for N concentration with a complete-combustion N analyzer (Leco 1000, Leco Corp., St. Joseph, MI)[1] and IVDDM by near-infrared reflectance spectroscopy (NIRS). Spectral data were collected on all samples, an average of 32 scans for each sample, with a NIR Systems 6500 spectrophotometer (Foss International, Silver Springs, MD) equipped with a static sample cup device. The NIRS was calibrated by combining 10% of the samples from this study with spectra from a library of pigeonpea samples (≈300 samples). In vitro digestible dry matter was determined for the calibration samples with the two-stage technique of Tilley and Terry (1963), as modified by Monson et al. (1969), were used to calibrate the NIRS system. Calibration and validation of equations for each plant component (IVDDM) were done with InfraSoft International (Port Matilda, PA), with partial least squares regressions (Shenk and Westerhaus, 1991). The IVDDM mean, SE of validation, and r^2 for the equation used were 588 g kg^{-1}, 29.8 g kg^{-1}, and 0.97, respectively.

All treatments were fixed in space and repeated on the same plot throughout the entire study period. The two pigeonpea lines were arranged in randomized complete block design with three replications. A split-split plot model was used to evaluate the lines as the main plot treatment (error a = rep × lines), years as the split plot treatment (error b = Rep × years within lines), and sampling dates as the split-split plot treatment (error c = residual error). Mean separations were calculated with LSDs using the pooled mean square error. The year × sampling date interaction term was significant ($P < 0.01$) for all response variables, so data were analyzed for each year as a repeated measure. Lines were determined different if F values were statistically significant at the $P < 0.05$ level. Year effects and year × sampling dates interactions were significant ($P < 0.01$) for all variables of interest, so data were reanalyzed and the results presented by year.

[1] Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by USDA and does not imply its approval to the exclusion of other products that may be suitable.

RESULTS AND DISCUSSION

The amount and distribution of precipitation during the growing season varied among years (Table 1). Precipitation in 1996 and 1997 was slightly greater (60 and 120 mm) than the 25-yr average of 500. Most of the precipitation in 1996 fell during July and August, which in this region are typically the driest months. Abnormally wet conditions prevailed throughout the 1997 growing season. Precipitation during the 1998 growing season was only 154 mm, which was ≈30% of the 25-yr average. Mean daily temperatures for the three growing seasons were 25°C in 1996, 23°C in 1997, and 26°C in 1998, compared with 25°C for the 25-yr average, but the 1997 growing season was characterized by especially cool temperatures and 1998 was warm relative to 1996 and 1997. Pigeonpea is a tropical legume that requires a base soil temperature of 12.8°C for germination and 58 heat units for emergence (Angus et al., 1980). As a second crop in a continuous winter wheat production system in the SGP, pigeonpea production may be more limited by available soil moisture than temperature.

Despite wide variation among years in growing conditions, no differences ($P < 0.05$) between lines or significant lines × year and lines × sampling date interactions were evident for any observations made in this experiment (Table 2). The lack of differences among lines could probably be attributed to similarity in maturity type and insensitivity to photoperiod.

Whole-Plant Responses

Total plant yield was similar between the 3 yr during the seedling development phase, but large differences occurred following canopy closure (Fig. 1). Higher total biomass production observed in 1996 was attributed to the unusual distribution of rainfall. Cool temperatures appeared to suppress biomass production of this tropical legume in 1997 despite above-normal precipitation. The reduced yield in 1998 was attributed to exceptionally dry conditions. The CGR calculated between 62 and 80 DAP was similar to that previously reported for medium- and long-duration pigeonpeas (Rao et al., 2002). In general, CGR for the first 80 DAP was lower than the CGR of the last three sampling dates. In 1996, CGR was 17.5 g m^{-2} d^{-1}, which was similar to the 17.1 g m^{-2} d^{-1} observed for early maturing pigeonpea lines

Table 1. Monthly precipitation and mean monthly ambient temperature for May through September, 1996 to 1998, and the 25-yr average at the study site.

Month	Precipitation				Ambient temperature			
	1996	1997	1998	25-yr Avg.	1996	1997	1998	25-yr Avg.
	mm				°C			
May	78	158	63	162	23.3	18.4	21.5	21.0
June	61	182	67	125	25.7	23.1	25.8	26.0
July	117	103	0	55	27.5	26.2	29.7	29.0
August	220	126	8	66	25.4	24.6	27.3	28.0
September	83	45	15	90	20.8	22.7	25.7	24.0
Total	559	615	154	498				

Table 2. Combined analysis of variance of total dry matter (DM), leaf, stem, and seed yield, and N and in vitro digestible dry matter (IVDDM) concentrations of two pigeonpea lines.

		DM				N				IVDDM			
Source of variation	df	Total	Leaf	Stem	Seed	Total	Leaf	Stem	Seed	Total	Leaf	Stem	Seed
Rep (R)	2	NS†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Lines (L)	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
Error (a)	2												
Year (Y)	2	**	**	**	**	**	**	**	**	**	**	**	**
Y × L	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Error (b)	8												
Day (D)	4	**	**	**	**	**	**	**	**	**	**	**	**
L × D	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × D	8	**	**	**	**	**	**	**	**	**	**	**	**
L × Y × D	8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Residual	48												

** Significant at the 0.01 level of probability.
† NS, not significant at the 0.05 level of probability.

grown at Patancheru, India (Sheldrake and Narayanan, 1979). Crop growth rates in the present study were 6.9 g m^{-2} d^{-1} in 1997 and 12.6 g m^{-2} d^{-1} in 1998.

Initial growth rates of pigeonpea are relatively low compared with other grain legumes (Muchow, 1985; Whiteman et al.,1985). Brakke and Gardner (1987) reported that a low rate of early growth in pigeonpea was associated with a lack of exposed cotyledons and small unifoliolate and trifoliolate leaves. These authors also reported that the small leaf area during early seedling development resulted in low light interception compared with other tropical legumes. Muchow (1985) reported that interception of photosynthetically active radiation was achieved in 42 DAP for soybeans, mungbean [*Vigna radiata* (L.) R. Wilczek], and cowpea [*Vigna unguiculata* (L.) Walp.], compared with 63 DAP for pigeonpea.

Stem, Leaf, and Grain Yields

Pigeonpea stem yields increased during the growing season within all 3 yr, but the rate of increase varied among years. Stem yield were highest in 1996, but stem yield of 560 kg ha^{-1} in 1998 were similar to those of

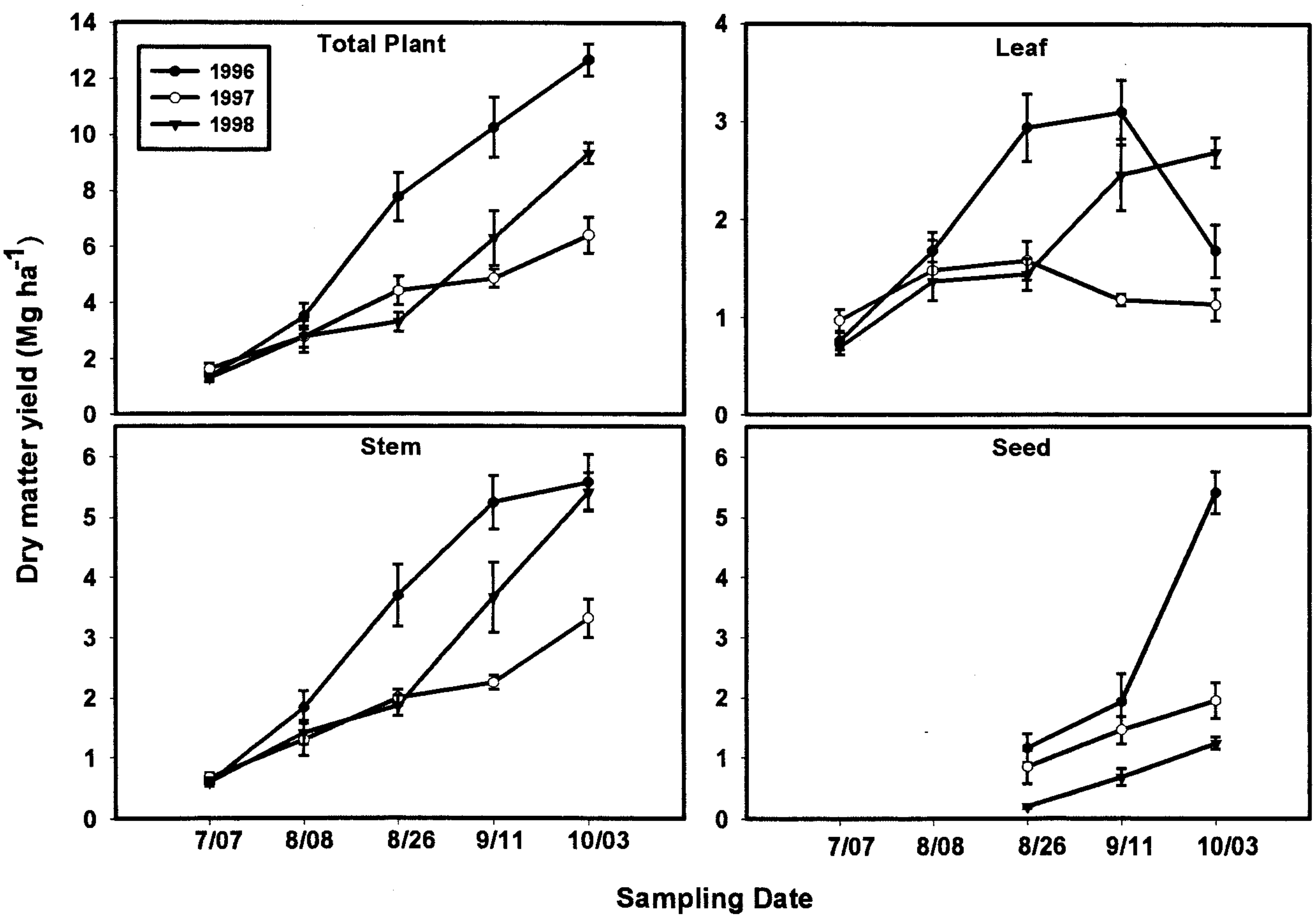

Fig. 1. Dry matter yield of aboveground whole plants, leaves, stems, and seed of pigeonpea, averaged across lines. Standard errors of the mean appear as vertical bars.

1996 by the last sampling date. Stem yields of both lines were lower ($P < 0.05$) in 1997, apparently affected by the excess moisture.

Temporal patterns of leaf yield were highly dissimilar ($P < 0.05$) across years. Leaf yields, like stems, also appeared to be adversely affected by wet growing conditions in 1997, and by a lack of precipitation early in the 1998 growing season. Greatest ($P < 0.05$) leaf yields occurred in 1996 at the third and fourth sampling dates, 80 and 96 DAP, but almost half of the peak leaf biomass was lost by 118 DAP. This could be attributed to senescence of older leaves and translocation of nutrients from leaves to a large seed crop.

Final seed yield in 1996 was 5.41 Mg ha^{-1}, as compared with 1.94 Mg ha^{-1} in 1997 and 1.23 Mg ha^{-1} in 1998. The increase in seed yield between the samplings on 11 September and 3 October of 150% corresponds to a similar decline in leaf biomass during the same period. Unlike leaf and stem yields, seed yields were lowest in 1998 on all sampling dates, which may be associated with low mobilization and translocation of nutrients from leaf and stem to seed during the dry growing conditions.

Forage and Seed Quality

Nitrogen concentration in whole plants and leaves generally declined during the growing season. It was highest in 1996 when growing conditions were most favorable (Fig. 2). Nitrogen concentration in leaves and stems at the last sampling date were similar among years and ranged from 36 to 33 g kg^{-1} and 9.3 to 9.0 g kg^{-1}, respectively. Stem N concentrations declined during the growing season in 1996 and were highest in that year, whereas N concentrations were more variable across time in 1997 and 1998, but increased slightly during the last three sampling dates in 1998, the drought year.

Seed N concentrations declined between all sample dates in the favorable growing season of 1996, but remained stable after declining between 80 (11 September) and 118 (3 October) DAP in other years. Year × sampling date interactions ($P < 0.01$) reflect the variations in patterns of change in N concentration, as with all other parameters observed in this study (Table 2). Seed N concentration at the last sampling date, averaged across years, was 26.1 g kg^{-1}. Nitrogen concentration of mature seed was greatest at almost 30 g kg^{-1} in the 1998 growing season (Fig. 2), when seed yields were least (Fig. 1). Seed N concentration was lowest (22 g kg^{-1}) in 1996 when seed yield was greatest. This reflected the distribution of a relatively uniform supply of N into varying seed biomass.

In vitro digestible dry matter of whole plant, leaf, and stem varied within and across years (Fig. 3). It generally declined early in the growing season but remained stable or rose slightly after midseason. Total plant IVDDM

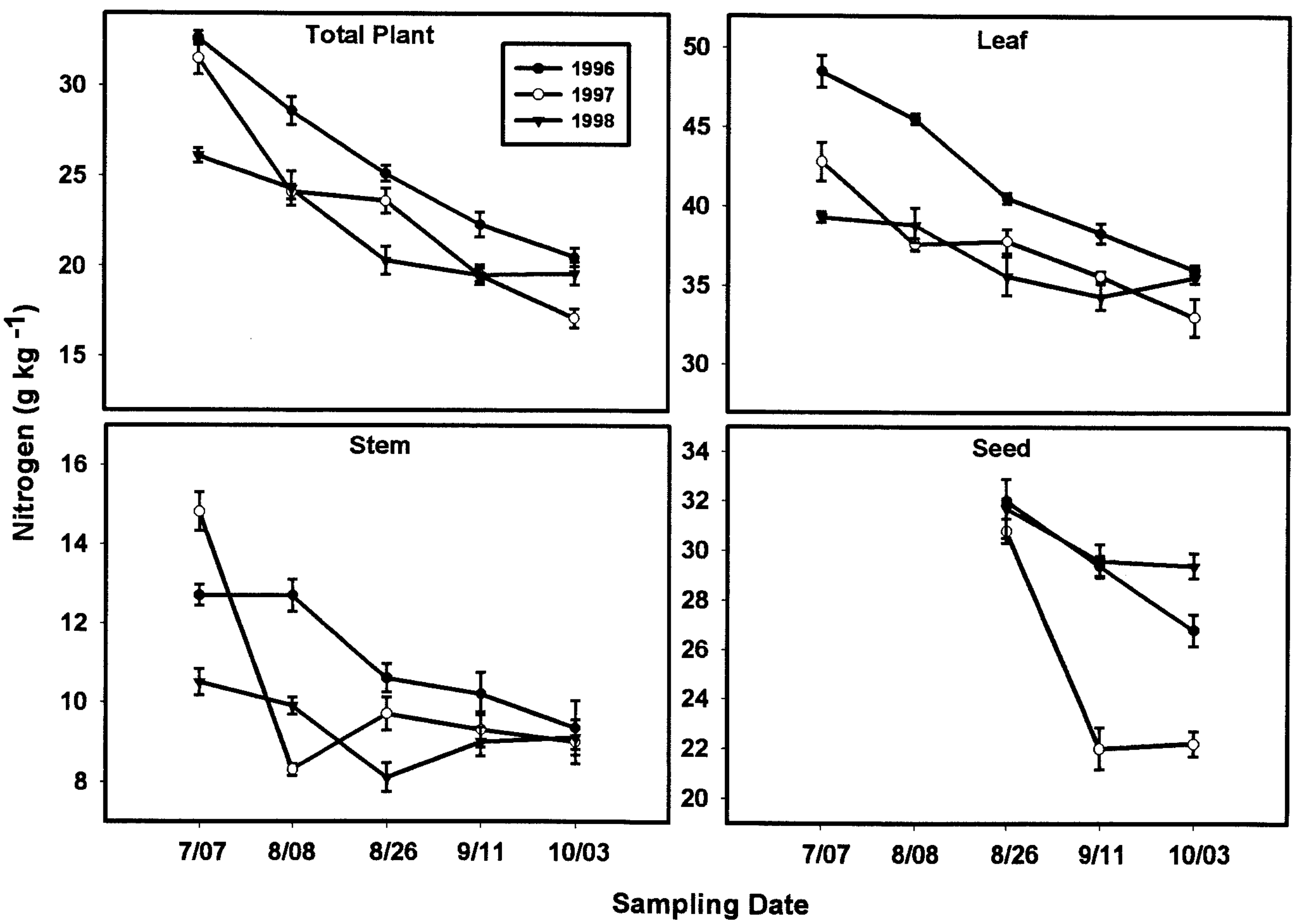

Fig. 2. Nitrogen concentration of aboveground whole plants, leaves, stems, and seed of pigeonpea, averaged across lines. Standard errors of the mean appear as vertical bars.

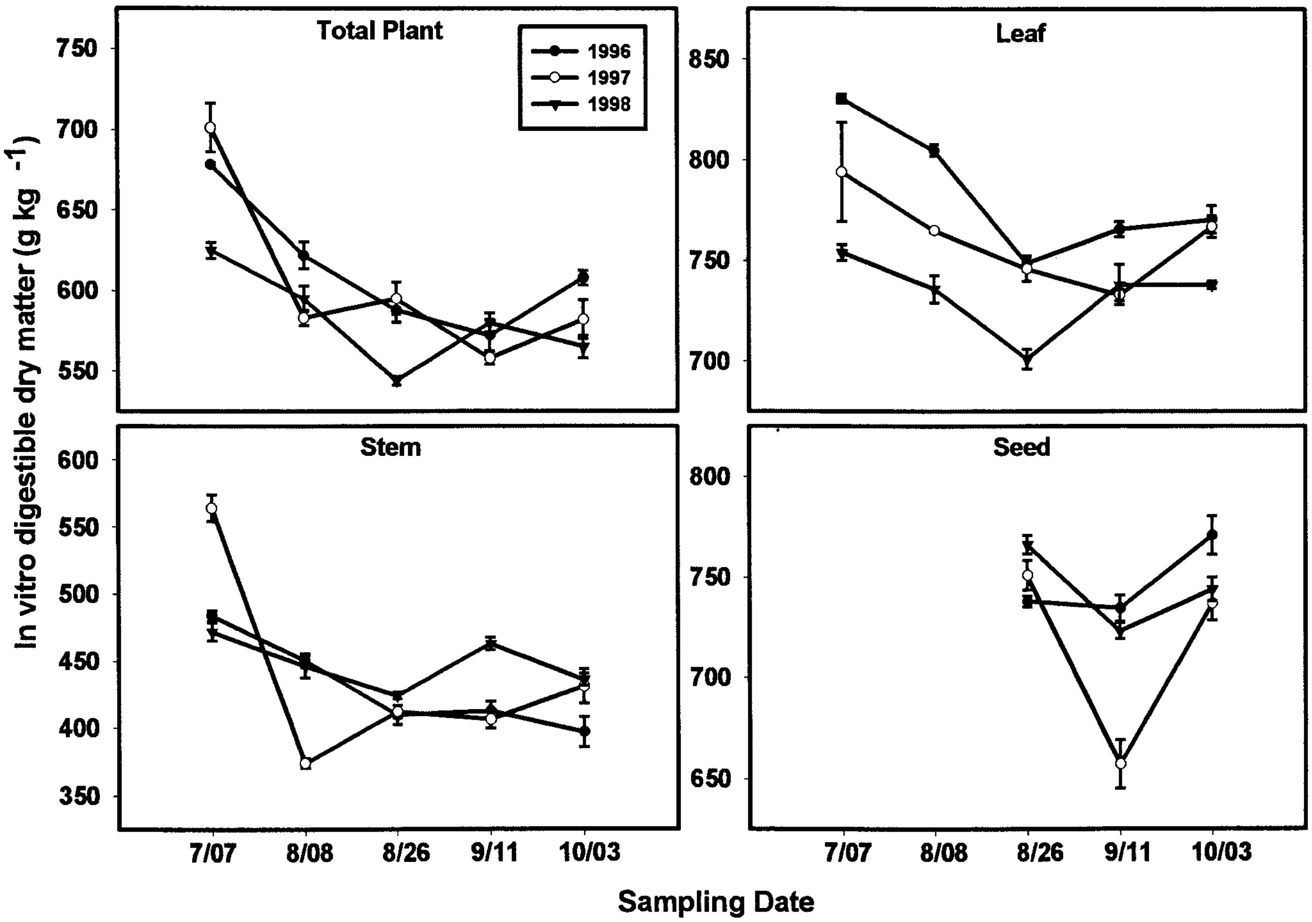

Fig. 3. In vitro digestible dry matter of aboveground whole plant, leaves, stems, and seed of pigeonpea, averaged across lines. Standard errors of the mean appear as vertical bars.

on last sampling date was highest in 1996 and lowest in 1998. Higher IVDDM of whole plants on the last sampling date in the 1996 growing season was explained by higher seed yield in that year (Fig. 1). For seed, very low IVDDM on 11 September in 1997 was likely because of visual observation of the pod borer (*Helicoverpa armigera* Hübner) being present, which also probably affected N concentration. On the last sampling date in all three growing seasons, IVDDM ranged from 738 to 770 g kg^{-1} for leaves, 396 to 436 g kg^{-1} for stems, and 737 to 770 g kg^{-1} for seed. Variation in weather patterns among years had minimal effects on the quality of leaves, stems, and seed.

CONCLUSIONS

Two early maturing pigeonpea lines produced large quantities of high-quality forage during the summer fallow period when other forages are inadequate. Total dry aboveground biomass yield ranged from 12.6 Mg ha^{-1} in 1996 to 6.4 Mg ha^{-1} in 1997. Average N concentration and IVDDM for whole plants were 23 g kg^{-1} and 580 g kg^{-1}, respectively, at midseason (80 DAP). At physiological maturity (118 DAP), whole plant N and IVDDM averaged 18.6 and 573 g kg$^{-1,}$ respectively. These results show that pigeonpea has the potential to produce moderate-quality forage during the forage-deficit period from August through October when the quality and quantity of perennial warm-season grasses typically decline. Forage quality was higher earlier in the growing season, but tannin concentration is high, which would reduce forage intake. We have observed that deer (*Odocoileus virginianus*) readily consumed pigeonpea soon after the onset of flowering, which occurs about 60 DAP.

Early maturing pigeonpea lines also have the potential to produce grain in the southern Great Plains. Seed yields of up to 5 Mg ha^{-1} represent a significant advantage of early maturing pigeonpea lines over medium- to late-maturing lines because high-quality seed can be harvested and fed as a protein supplement for livestock. A growing season of only 118 d, ending in mid-October, allows the opportunity to grow pigeonpeas to maturity between winter wheat crops. Medium- and late-maturing varieties grown at our location required 200 to 220 d to mature, and many of these had not even flowered by the time wheat should have been planted. At final harvest, early maturing pigeonpea had sufficient herbage present with moderate quality that should provide sufficient postharvest grazing.

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